



Stratal Slicing: An Application for Seismic Sedimentology

Staffan Kristian Van Dyke
Van Dyke Geoscience; Houston, TX, USA;
Email: staffan.vandyke@vandykegeoscience.com

Received: 11 August 2015, Revised Received: 12 October 2015, Accepted: 14 October 2015

Abstract

This paper presents a case study related to the application of seismic stratal slicing for analyzing the sedimentologic properties of subsurface deposits. Stratal slicing is the process of flattening a seismic dataset with reference to an interpolated, continuous, 3-dimensional surface, known as a horizon (Zeng et al, 1998a; Zeng et al, 1998b; Van Dyke, 2006; Zeng, 2010). An interpreted seismic horizon, which forms the basis of a stratal slice subvolume, is generally considered to represent a time equivalent surface. This surface may characterize a lithologic boundary, a disconformity, a condensed section, among other geologically significant time boundaries. Time slices are simply the manifestation of values sampled along a purely horizontal cross-section taken across the seismic survey, while stratal slices use phantom horizons to image the subtle stratigraphic features embedded throughout the seismic wavelet.

Keywords: Stratal slice, seismic sedimentology, channel, imaging, horizon, principle of original horizontality

Introduction

The stratal slice technique originated in the late 1990's, amid research studies designed to improve the viewing and interpretation of 3-dimensional seismic data. The research was primarily conducted by Dr. Hongliu Zeng, now a Senior Research Scientist for the Bureau of Economic Geology at the University of Texas, in Austin.

Although much information can be ascertained from time slice extractions (Fig. 1a), the process of stratal slicing is considered to be the preferable methodology for studying the sedimentological nature of subsurface deposits and the processes that formed them (Fig. 1b). Stratal slice phantom

horizons are designed to follow paleodepositional surfaces, removing the variation of seismic attributes, e.g., amplitude, across different strata, allowing for more sedimentologically representative parts of the seismic signal to manifest themselves.

The idea of stratal slicing is simple. As one of Steno's Laws states, the Principle of Original Horizontality, depositional sequences are laid down in a horizontal manner. These depositional bedding planes are represented by interpreted seismic horizons. The seismic horizons record the detail from coeval, time equivalent, surfaces throughout the seismic volume. It is the nature of interpreted horizons to undulate in space as they follow wavelet picks from trace to trace [trough → trough, (+/-)]

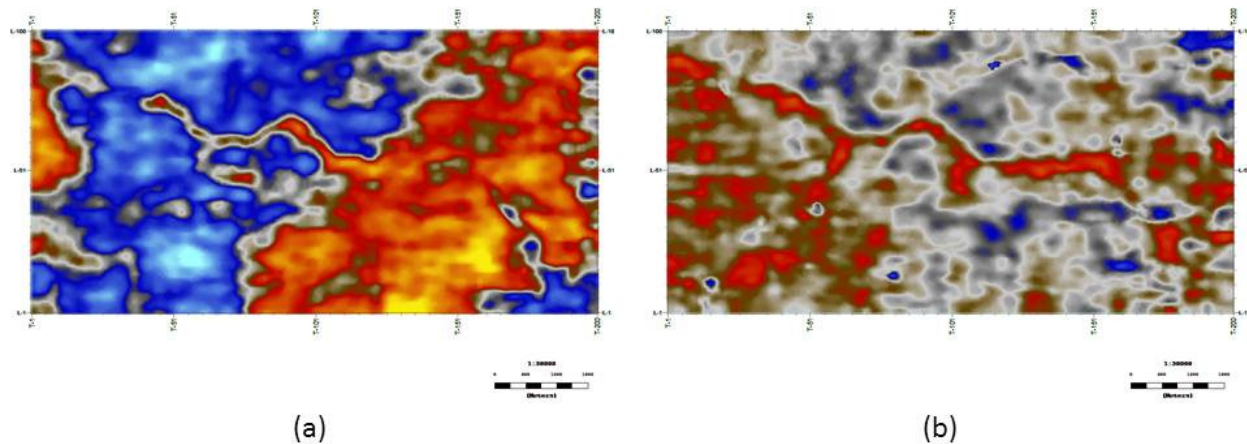


Fig. 1: A typical seismic time slice extraction of amplitude values showing the morphologic pattern of a channel, whereby variations of seismic amplitude reflects different strata or changes of acoustic properties within the same stratum (a); and the resultant stratal slice extraction showing much more internal detail with regard to the channel's continuity (b).

zero-crossing \rightarrow (+/-) zero-crossing, or peak \rightarrow peak] (Fig. 2). Geoscientists map seismic events by adhering to soundly based reasoning behind the stratigraphic, sedimentologic, and structural nature of the deposits being interpreted. It is a carefully interpreted horizon that forms the basis of a successful stratal slice subvolume.

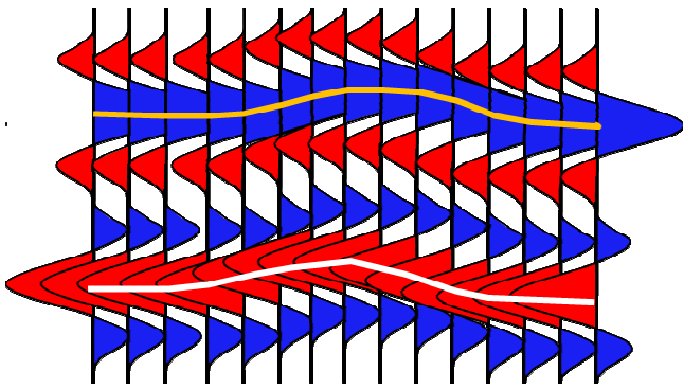


Fig. 2: Interpreted seismic horizons are mapped as time equivalent surfaces that undulate in space from trace pick to trace pick (image from Bianco, 2011).

Due to the complex stratigraphic variations sampled across seismic traces by interpreted horizons, it has been demonstrated that genetically related depositional elements are better represented via stratal slice phantom horizons (either above or

below the referenced horizon) than time slice extractions. These phantom horizons illuminate the acoustic properties of the deposits stratigraphically adjacent to the interpreted horizon, rather than being limited to the maxima/minima based horizon interpretations to adjacent wavelet lobes within the trace. Since its inception, the tradition of viewing 3D seismic data in its primary, orthogonal axes (i.e., time slicing), has since shown itself to be limited in its approach to viewing, and thus, interpreting, ones data.

Objectives

The purpose of this study is to demonstrate the increased stratigraphic and sedimentologic detail gained from applying the stratal slice technique to a 3-dimensional seismic dataset. Although traditional time slice extractions (Fig. 1a) image portions of the internal channel elements, its proximal levees, and a splay deposit, they are much harder to interpret because they do not follow depositional bedding planes. This paper aims to highlight the additional benefits that stratal slicing can deliver by direct evidence of more continuously imaged depositional sequences within the subvolume.

The example used in this study comes from a publically available 3D seismic dataset known as the Stratton Field dataset. It is located in south Texas, in the northwestern portion of the Gulf Coast Basin. The main sedimentary package being studied for this paper is the Oligocene Frio Formation; it is characterized by a high sediment-supplied fluvial system distinguished by rapid deposition and high subsidence rates (Levey et al, 1994). Multiple low impedance seismic events were mapped throughout the study area within a roughly 3000 ft. thick stratigraphic column (Figs. 3 and 4).

Most prominent in the seismic survey is a large syndepositional growth fault capped by a progradational sequence exhibiting the characteristics of a meandering stream environment. The horizons mapped in this study were interpreted within this fluvial dominated region. The horizon names were prefaced “CS” for channel system, and suffixed with an “ip” for interpolated. After these seismic events, represented by irregular topological surfaces, again, known as horizons, were interpreted, the stratal slice subvolume construction began.

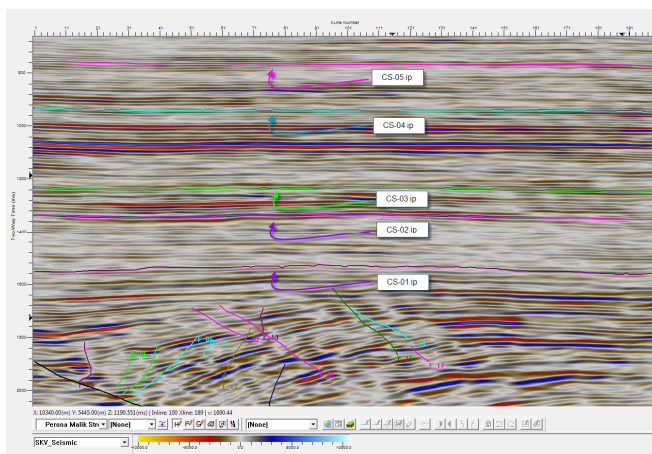


Fig. 3: Seismic vertical section view showing prominent growth fault at base of interval capped by a progradational unit topped by the horizon CS_05 ip in pink with the horizon CS_01 ip at its base in purple.

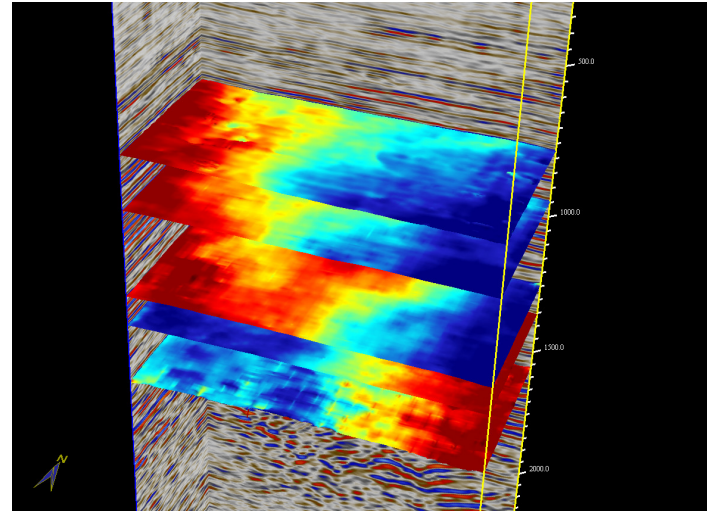


Fig. 4: CS_01 ip – CS_05 ip time structure maps shown in 3D Euclidean space.

The software used in this study was AttributeStudio™; the accompanying diagrams and figures derive from this source. Interactive analysis workflows based on seismic attributes calculated from or extracted to a “Strata-grid” are demonstrated as more effective and powerful than traditional linear workflows (Wen, 2011). Stratal slicing within a Strata-grid is much simpler than having to go through the arduous process of volume flattening, rather, phantom horizons are calculated at user-defined intervals organized to follow paleodepositional surfaces. This process is more dynamic because it is not limited to time slice sample unit range/subvolume interval range, as an analog signal can theoretically be sampled infinite times, as can be done with Strata-grids (Fig. 5).

Regardless of the software being used to build a stratal slice subvolume, the first step is to measure the amount of time (s)/depth (m) the volume is to be flattened by (this is not necessary when bounding by two or more horizons). Generally, a good rule of thumb is to backstrip the depositional history of the seismic reflectors either above or below the reference horizon to other time equivalent stratigraphic events. After volume flattening, the

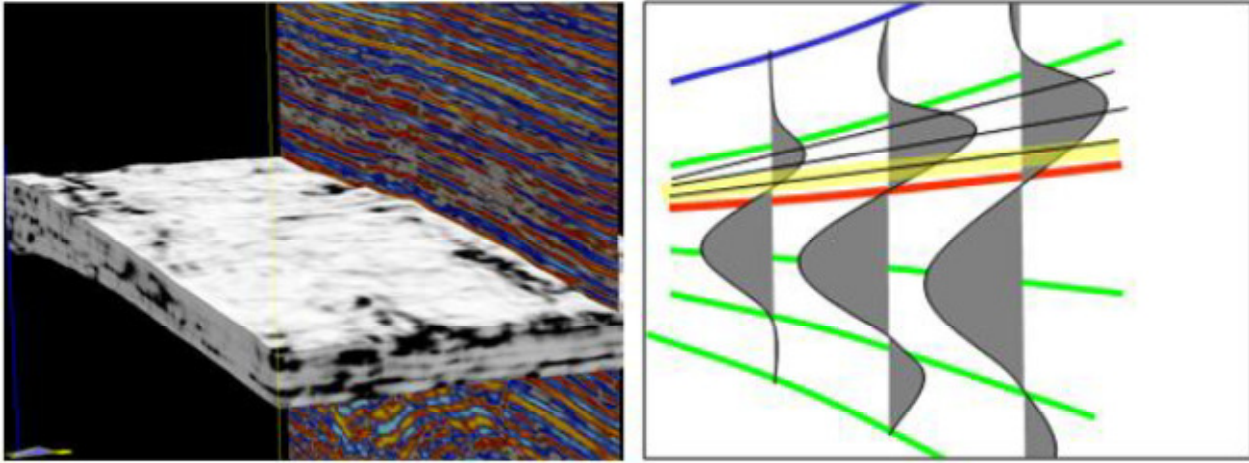


Fig. 5: The concept of stratal slices and their associated wavelet positions extracted along adjacent traces (Wen, 2011).

resultant stratal slice subvolume is considered to more accurately represent the environment's depositional history.

While preparing stratal slice subvolumes, some software packages are more versatile than others; in AttributeStudio™, there is an additional step where the user defines the appropriate type of lithologic stacking pattern present (Fig. 6). Proportional slices were used in this study as the stratigraphy of the reflectors exhibit a subparallel nature between the control horizons. 800 slices were extracted at equally spaced intervals over a 400 ms time sample range (Fig. 7).

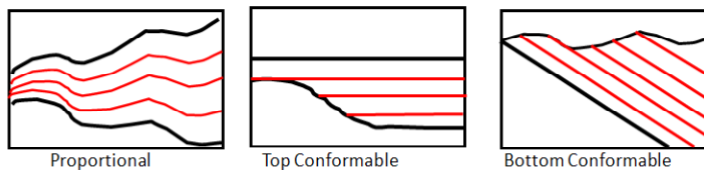


Fig. 6: AttributeStudio™ Strata-grids: Proportional, Top Conformable, or Bottom Conformable.

The final step is to extract all seismic attributes (instantaneous/geometrical/response/etc.) to the stratal slice subvolume. The extractions used in this study include: instantaneous phase, response frequency, most negative curvature, among many

others. In accordance with all of these attributes, spectral decomposition was also run and extracted. Multiple realizations of spectral decomposition were executed to evaluate the differing responses from the varied algorithms (discrete Fourier transform [DFT]; continuous wavelet transform [CWT]; time–frequency continuous wavelet transform [TFCWT]; S-transform [ST]; and continuous wavelet packet transform [CWPT]).

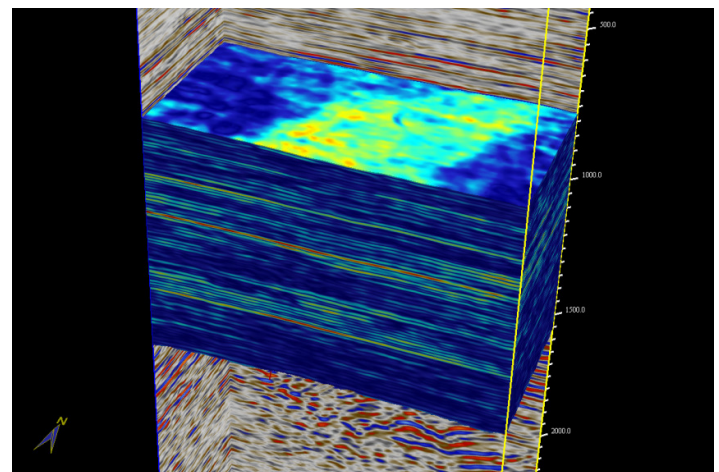


Fig. 7: Proportionally sliced Strata-grid with 800 equally spaced intervals; poststack amplitude response of the top of the Strata-grid is shown.

The stratal slice intervals were then “sliced” along the phantom horizon planes revealing the hidden

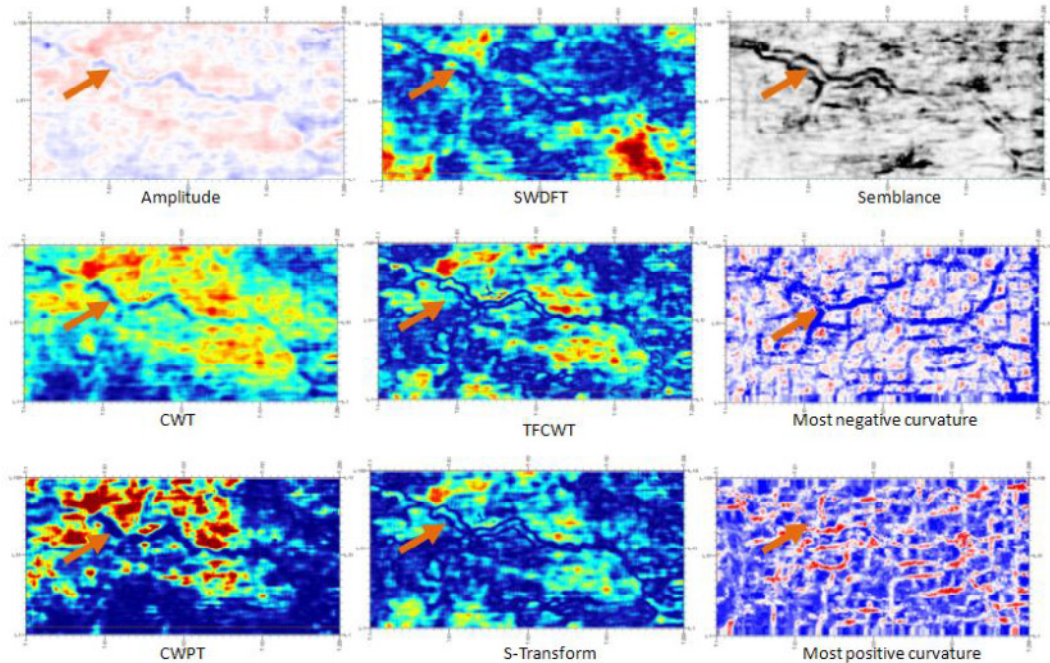


Fig. 8: A clearly defined fluvial channel system can be seen from the iso-frequency Strata-grid slices calculated from the five different spectral decomposition algorithms, each exhibiting varying characteristic elements of the deposit (Wen, 2011).

responses found within the seismic wavelets. The prodigious amount of seismic attributes extracted within the stratal slice subvolume allowed for spectacular viewing results of the fluvial system's reservoir characteristics and geomorphologic patterns (Figs. 8, 9, and 10).

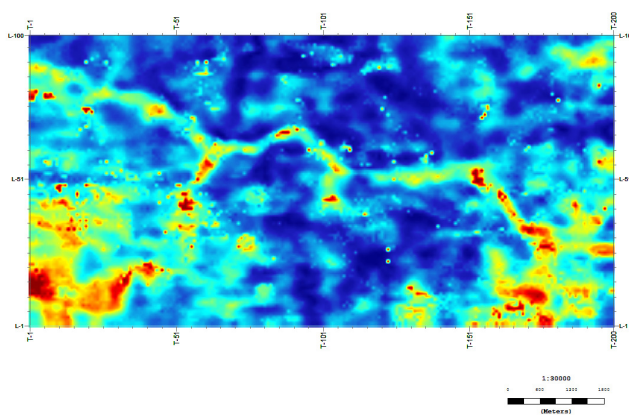


Fig. 9: Fluvial channel morphology clearly imaged with the sweetness attribute, where the lower frequency, high amplitude, colors are believed to represent sandstones (red/orange/yellow), while the higher frequency colors are interpreted to represent shales (blue/indigo/violet).

Discussion

The concept of stratal slicing, by sampling values at predefined intervals throughout wavelet positions along adjacent traces, can yield a wealth of information to the stratigraphic, sedimentologic, and geomorphologic nature of the deposits being studied. For example, the “proportionally sliced” Strata-grid used in this project, with 800 equally spaced phantom horizons imaged details found in most fluvial environments, e.g., the channel thalweg, associated proximal levees, and a splay deposit (Figs. 7, 8, and 9).

This clearly imaged channel system can be seen in the iso-frequency Strata-grid slices calculated from the five different spectral decomposition algorithms, each gleaning a slightly different realization of the properties found within the deposit. The sweetness attribute was used as a sand/shale indicator, where the lower frequency, high amplitude, colors are believed to represent sandstones

(red/orange/yellow), while the higher frequency colors are interpreted to represent shales (blue/indigo/violet). Channel boundaries are best imaged with the semblance extraction as compared to other attributes (Fig. 9).

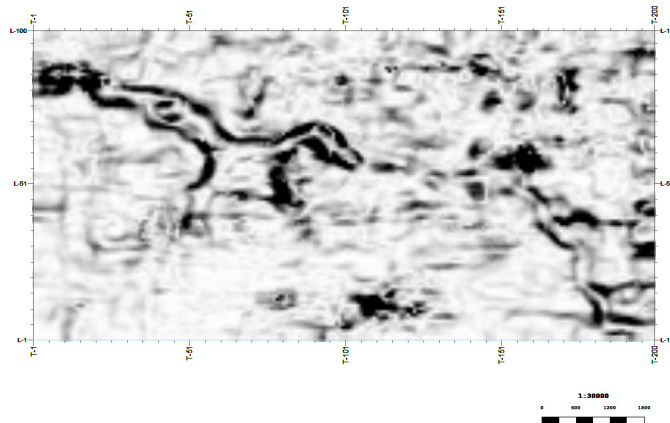


Fig. 10: Channel architectural elements within a meandering fluvial system showing the channel thalweg bounded by proximal levees and a possible splay deposit (seismic attribute: semblance).

Conclusion

The stratal slice technique captures a more complete depositional history for an associated stratigraphic interval than compared to time slices taken through the same interval, at least many tens to hundreds of sample units above/beneath the flattened horizon (i.e., either depth [m] or time [s]). Additionally, greater sedimentologic and stratigraphic detail may be gained when using two or more horizons as input controls for stratal slice subvolumes (one stratigraphically higher unit and one stratigraphically lower unit). These can then be “sliced” as proportional slices, top-conformable slices, or bottom-conformable slices, each being uniquely suited to handle different depositional contacts and bedding geometries. With this unique approach, depositional environments recorded within 3-dimensional seismic data, can be imaged

more easily, ultimately lending itself to a more accurate geologic interpretation.

Acknowledgements

Dr. Hongliu Zeng, along with my former colleagues from Geomodeling, Dr. Renjun Wen and Rex Knepp, are thanked for their invaluable insight and brainstorming sessions, all of which led to a much improved final paper.

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